



# The Cost-Effectiveness of Surgical Fixation of Distal Radius Fractures: A Computer Model-Based Evaluation of Three Operative Modalities

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**Abstract**

*Background:* There is no consensus on the optimal fixation method for patients who require surgical management for distal radius fractures. We used a cost-effectiveness analysis to determine which of three modalities: closed reduction and percutaneous pinning (CRPP), external fixation (EF), or open reduction internal fixation (ORIF), offers the best value.

*Methods:* We developed a state-transition computerized Markov model that simulates cohorts of patients undergoing surgery for distal radius fracture, projecting short- and long-term health outcomes and costs. Simulations began at age 50 and were run over lifetime. The model inputs were *transition probabilities*, *quality of life values*, and *costs*. Transition probabilities incorporated postsurgical complication rates derived from the literature, which were categorized as postsurgical minor (e.g. infection), major non-operative (e.g. neuropathy), and major operative (e.g. tendon rupture) complications and loss of reduction. Quality of life values incorporated clinical outcomes, also derived from the literature. Costs incorporated Medicare reimbursement schedules in 2016 U.S. dollars. The simulation was conducted from two cost reference perspectives: *health care payer*, which accounts for health-related costs, and *societal*, which accounts for indirect costs such as lost productivity. The model outputs were total costs and quality-adjusted life-years (QALYs), discounted at 3% per year. We then calculated an incremental cost-effectiveness ratio (ICER) by dividing the differences in costs by the difference in QALYs between two comparators to determine the value of a given procedure. ICERs were evaluated against willingness-to-pay thresholds (WTP) of \$50,000 and \$100,000 per QALY. If the ICER for a procedure was less than the WTP, then it could be considered a cost-effective alternative to its comparator. We conducted deterministic and probabilistic sensitivity analyses to evaluate the impact of data uncertainty on the results.

*Results:* The total QALYs were 13.99, 13.98, and 13.89 for CRPP, ORIF, and EF, respectively. From the health care payer perspective, total costs were \$8,735 (CRPP), \$11,125 (ORIF), and \$11,759 (EF). CRPP dominated (i.e. produced greater QALYs at lower costs than) ORIF and EF. From the societal perspective, total costs were \$19,214 (ORIF), \$19,435 (CRPP), and \$22,295 (EF). The ICER for CRPP compared to ORIF was \$21,058 per QALY and EF remained dominated. In probabilistic sensitivity analysis, ORIF was cost-effective roughly 50% of the time compared to roughly 45% for CRPP.

*Conclusions:* CRPP is the cost-effective method at the base case from both health care payer and societal perspectives. When considering data uncertainty in sensitivity analysis, ORIF appears to be more cost-effective; however, there is only a 5 to 10% difference in the frequency of probability combinations in favor of ORIF. The current degree of uncertainty in the data produces difficulty in distinguishing either CRPP or ORIF as being more cost-effective overall and thus may be left to surgeon and patient shared decision-making.

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## Glossary of Terms

### CRPP (closed reduction percutaneous pinning)

Treatment of a fracture that involves manual manipulation of the bony fragments back into appropriate position without a surgical exposure. This is followed by insertion of thin metallic wires through the skin to hold the fragments in place. These constructs are usually casted for a period of 6-8 weeks.

### CRPS (complex regional pain syndrome)

Also known as reflex sympathetic dystrophy (RSD); a chronic pain disorder that affects a limb following injury or surgery. Thought to be due to damage to or malfunctioning of nearby nerves, this condition is characterized by longstanding and severe pain, swelling, loss of function, and changes to the skin and bone.

### DRF (distal radius fracture)

A fracture or break in the radius, which is one of two bones located in the forearm. The fracture site is located in the distal portion of the radius, which corresponds to the area closer to the wrist. Typically sustained in an osteoporotic patient who falls on an outstretched hand or a younger patient sustaining high-energy trauma, this fracture is characterized by pain, swelling, and sometimes gross deformity to the wrist. Fractures that do not involve the wrist joint or are not substantially displaced can be treated nonoperatively with closed reduction and cast immobilization. When these fractures involve the wrist joint space, are substantially displaced or comminuted, or prove to be unstable, they may require surgical fixation.

### EF (external fixation)

Treatment of a fracture that inserts pins through the skin into the bones across a fracture site. The pins are then held in place on the outside by a fixator or frame, which distracts the bones across the fracture site to attain proper alignment and rigid fixation. The fixator is usually maintained for a period of 6-8 weeks.

### ICER (incremental cost-effectiveness ratio)

$$ICER = \frac{C_2 - C_1}{E_2 - E_1}$$

Where  $C_2$  and  $E_2$  are the cost and effectiveness (e.g. QALYs) of an intervention group and  $C_1$  and  $E_1$  are the cost and effectiveness of the comparator, respectively. By calculating the difference in costs divided by the difference in QALYs between an intervention and its comparator, the ICER provides the additional cost-per-QALY gained in switching between interventions. As such, the ICER is a determinant of the value of a surgical procedure. ICERs are evaluated against a willingness-to-pay threshold (see: WTP).

**ORIF (open reduction internal fixation)**

A surgical treatment of a fracture that involves using a surgical exposure to gain access to the fracture site in order to reduce, or put the bone fragments back into, proper anatomic position. The bony fragments are then held in place with a plate and screw construct.

**QALY (quality-adjusted life-year)**

A measurement of disease burden on a patient's quality of life. A QALY is rated on a scale of 0 to 1, where 1 correlates to a year of perfect health, <1 correlates to a year of less than perfect health, and 0 corresponds to death.

**WTP (willingness-to-pay)**

A theoretical threshold or limit cost above which society is not willing to spend additional resources to gain additional QALYs. The WTP threshold varies for different societies and cultures; typically, in the United States, WTP thresholds of \$50,000 and \$100,000 per QALY are utilized. If an intervention's ICER falls below the WTP threshold, it can be considered a cost-effective alternative to its comparator.

## Introduction

Distal radius fractures (DRFs) are one of the most common injuries of the musculoskeletal system, typically sustained in elderly, osteoporotic patients who fall on an outstretched hand or in younger patients who sustain high-energy trauma<sup>1</sup>. DRFs that are extra-articular and that stably demonstrate little displacement on static radiographs (e.g. <5 mm radial shortening, <5° dorsal angulation) typically can be treated nonoperatively with closed reduction and cast immobilization<sup>2</sup>. However, DRFs that are displaced intra-articularly, severely comminuted, substantially displaced (e.g. >5 mm radial shortening, >5° dorsal angulation), or prove to be dynamically unstable may require surgical fixation<sup>2</sup>.

Options for surgical fixation of DRFs include closed reduction and percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF)<sup>1</sup>. CRPP involves closed manipulation of the fracture to restore normal alignment followed by percutaneous pin insertion to hold the bony fragments. CRPP is considered a less invasive, inexpensive, and effective technique<sup>3-6</sup>; however, some question its capability to consistently achieve and maintain fracture reduction<sup>7-9</sup>. EF is a well-established, time-honored technique that involves using percutaneous pins held together with an external frame or fixator to attain fracture alignment and rigid fixation. However, over time, this technique has fallen out of favor and has been associated with high rates of complications, including infections and complex regional pain syndrome (CRPS)<sup>3,10,11</sup>. ORIF involves an operative exposure to the fracture site to restore anatomic alignment and to hold the fracture in place with a plate and screw construct. ORIF is both the most invasive and the most expensive option, but it is also the most widely-used technique with a growing trend towards the use of volar locked plating technologies<sup>1,12-14</sup>.

Based on currently available evidence, there is no consensus on the optimal fixation method for DRFs<sup>1</sup>, despite the growing trend towards volar locked plating ORIF<sup>1,15,16</sup>. Recent randomized controlled trials

conducted in the United Kingdom have demonstrated short-term (i.e. 6- to 12-week) postoperative functional benefits for patients with DRFs undergoing ORIF compared to CRPP; however, they did not elucidate any long-term functional differences between the two treatments<sup>12,13</sup>. Despite this evidence, there is a belief in the literature and in the orthopaedic community that the additional costs of ORIF—compared to CRPP or EF—are offset by more durable fixation<sup>16</sup>, shorter periods of immobilization, and earlier return to work, although little evidence supports these claims<sup>6,14,16</sup>. Given a renewed emphasis on value-based health care in current political and economic climates, it is becoming increasingly important to delineate the value provided by health care interventions<sup>17,18</sup>.

The cost-effectiveness analysis is one of the most commonly utilized tools in economic evaluation of medical care and assesses the value of an intervention relative to a comparator by assessing differences in costs and subsequent quality of life<sup>19</sup>. To date, cost-effectiveness studies comparing CRPP, ORIF, and EF techniques have been conflicting. Tubeuf et al.<sup>12</sup> and Karantana et al.<sup>13</sup> conducted cost-effectiveness analyses alongside their United Kingdom-based randomized controlled trials and found ORIF to not be a cost-effective alternative to CRPP with incremental cost-effectiveness ratios (ICERs) of £40,060 and £89,322 per quality-adjusted life-year (QALY), respectively, which were both above the willingness-to-pay (WTP) threshold of £30,000 per QALY. Although based on strong randomized controlled trial designs, these data are limited by very short (i.e. 1-year) time horizons and by the inability to project costs and outcomes over patients' lifetimes. In addition, the results cannot be directly translated to a United States perspective given differing payment models and WTP thresholds.

Only one United States-based study by Shauver et al.<sup>11</sup> has analyzed all three surgical options in addition to casting and immobilization in the elderly subpopulation. This 10-year decision tree model found ORIF to cost less while offering more benefits than CRPP and EF<sup>12</sup>. Given that this model utilized a simple



decision tree that applied static quality of life values to a 10-year period following fracture fixation, it did not account for dynamic changes in quality of life that can occur over time from fracture healing or from lingering postsurgical complications. In addition, this study focused solely on an elderly subpopulation, the results of which cannot be expanded to a younger or an all-comer population that sustains DRFs.

Our objective was therefore to utilize a more detailed, computerized Markov state-transition model to simulate cohorts of patients undergoing CRPP, ORIF, and EF surgical fixation methods for DRFs and to project the postsurgical cost and clinical outcomes over the patients' remaining lifetimes. The goal will be to utilize the model to examine the lifetime cost-effectiveness of CRPP, ORIF, and EF to elucidate which fixation method offers the best value for patients.

## Materials and Methods

### *Analytic Overview*

We constructed a computerized, state-transition Markov model for patients with a DRF that could be treated appropriately with any of three methods: CRPP, ORIF, or EF. The model was created using TreeAge Pro software<sup>20</sup> and simulates the course of surgery as a series of transitions between health states over time, dictated by transition probabilities<sup>21</sup>. Each health state is characterized by a quality of life value (i.e. utility) and costs.

An utility is a measurement of disease burden on a patient's quality of life<sup>22</sup> and is rated on a 0 to 1 scale where 1 defines a year of perfect health, <1 defines a year of suboptimal health, and 0 defines death<sup>23</sup>. Costs reflect the sum of resources utilized within each health state, both paid and unpaid. As the model proceeds forward, time spent experiencing the utility of each health state is aggregated into quality-adjusted life-years (QALYs). We adhered to the design and reporting recommendations of the Second Panel on Cost-Effectiveness in Health and Medicine and ran our model in accordance with two base case perspectives: a *health care payer perspective* that accounts for direct health-related costs, and a *societal perspective* that incorporates direct health-related costs in addition to indirect costs such as unpaid caregiver-time and productivity costs<sup>23</sup>. We adhered to reporting guidelines per the Consolidated Health Economic Evaluation Reporting Standards (CHEERS)<sup>24</sup>.

The model outcomes of QALYs and costs are incorporated into an incremental cost-effectiveness ratio (ICER), defined as the difference in costs divided by the difference in QALYs between two treatments. By providing the additional cost-per-QALY gained in shifting between interventions, ICERs quantify the value of a procedure<sup>25</sup>. ICERs are evaluated in reference to a willingness-to-pay (WTP) threshold, which is defined as the maximum threshold cost above which society is no longer willing to spend for additional

QALYs<sup>26</sup>. We used conventional WTP thresholds of \$50,000 and \$100,000 per QALY<sup>27</sup>. By convention, a treatment is considered cost-effective if its ICER falls below the WTP threshold. A treatment is “dominated” if it costs more and produces fewer QALYs than its comparator.

We conducted sensitivity analyses to evaluate the impact of data input uncertainty on our results. These analyses were conducted in two ways: deterministic sensitivity analyses and probabilistic sensitivity analyses. Deterministic analyses varied input parameters (e.g. transition probabilities, utility values, and costs) over discrete ranges. Probabilistic analyses varied these same input parameters over distributions. We portrayed the results of these sensitivity analyses in cost-acceptability curves displaying the likelihood that each method would be found to be cost-effective.

### *Model Structure*

Figure I depicts the structure of the model. Patients enter the model at initial surgery. During surgery, patients can suffer perioperative medical complications, which includes such problems as myocardial infarction, pulmonary embolism, and stroke<sup>28</sup>. After primary surgery, patients can enter optimal or suboptimal health states. The optimal category captures patients with no postsurgical complications and adequate fixation. The suboptimal category captures patients who have experienced unresolved postsurgical orthopaedic complications or inadequate/failed reductions. Postsurgical orthopaedic complications are grouped into three categories: minor complications (superficial pin or wound infections; tenosynovitis/tendonitis); major non-operative complications with no additional surgery (non-operative nerve injuries, neuropathies, or carpal tunnel syndrome treated conservatively; CRPS); and major operative complications requiring further surgery (deep infection, tendon rupture, operative nerve injuries, hardware failure/removal)<sup>29</sup>.

Over the initial 6-week cycle, patients with major orthopaedic complications requiring surgery can receive revision surgery and can return to the optimal state if no additional/persistent complications or can remain in the suboptimal state. Likewise, within the first 12 weeks of primary fixation, patients with failed or inadequate reduction within the suboptimal state may undergo an ORIF as a revision procedure. Revision outcomes from revision ORIF or from major orthopaedic complications requiring surgery are also categorized into optimal and suboptimal states. During each 6-week period, patients can die according to their age-stratified mortality. Patients enter the model at age 50 based on a literature average of age at presentation for studies with no age exclusion criteria<sup>3-5,11,15,30-34</sup> (i.e. an all-comer population). Acknowledging that the incidence of DRFs follows a bimodal distribution, in sensitivity analysis, we conducted age-stratified analysis for two age groups—25- and 65-years—to evaluate the effect of input age on the results.

#### *Transition probabilities*

The probability of perioperative medical complications (e.g. myocardial infarction, stroke) was derived from literature that studied 30-day postoperative complications following ORIF for DRFs<sup>28</sup>. We assumed that the risk of perioperative medical complications was similar for all three procedures and was estimated at 0.8%<sup>28</sup>.

Following primary fixation, the probability of entering the suboptimal state (vs. optimal state) was determined by the composite probabilities of reduction loss and postsurgical orthopaedic complications (Table 1). These data were derived from randomized controlled trials and prospective cohort studies that were identified via a PRISMA-methods compliant systematic review of the literature (Appendix). We determined that of the patients receiving CRPP, ORIF, and EF fixation, that 4% for CRPP, 1% for ORIF, and 11% for EF would sustain postsurgical loss of reduction (Table 1). Of these patients with postsurgical loss

of reduction, an average of 77% of CRPP<sup>3-6,8,31,35</sup>, 67% of ORIF<sup>6,11,15,33,36-38</sup>, and 63% of EF fixations<sup>3,31,34,36,39-</sup>

<sup>41</sup> received revision ORIFs within 6-weeks and could then enter optimal or suboptimal post-revision states.

We assumed the transition probabilities for a revision ORIF would be similar to those of a primary ORIF within the model.

Table 1 depicts the total rates for minor, major non-operative, and major operative orthopaedic complications following CRPP, ORIF, and EF. Of patients suffering superficial or pin infections, we observed that 85% of CRPP pin track infections<sup>3-6,32,35,42</sup>, 94% of ORIF surgical site wound infections<sup>5,6</sup>, and 94% of EF pin track infections<sup>3,31,33,34,39,43-45</sup> would receive antibiotics. Following antibiotic administration, we observed in the literature that 15% of CRPP pin infections<sup>3,4,30,32,35,42</sup> and 31% of EF pin infections<sup>31,33,34,39,43-45</sup> required subsequent pin or fixator removal. No data exist on the probability of antibiotic failure for surgical site infections following ORIF for DRFs, so we assumed an antibiotic failure rate of 1.76% from a study on wound healing complications after ORIF for calcaneal fractures<sup>46</sup>.

We assumed that all cases of inflammatory tenosynovitis and tendonitis following CRPP, ORIF, or EF surgical fixation would initially receive conservative treatment. Based off of a systematic review that studied the probability of recovery from cortisone injection for tenosynovitis, we estimated that 16% of patients would fail conservative treatment for tenosynovitis/tendonitis following CRPP and EF, requiring an additional methylprednisolone injection<sup>47</sup>. Following ORIF, we observed in the literature that 70% of patients failed conservative treatment and underwent hardware removal for tendonitis due to direct hardware irritation or subluxation of the tendons over the hardware<sup>4,11,15,33,34,36,37,39,41</sup>. For major non-operative orthopaedic complications, we assumed that all patients with CRPS or non-operative nerve injuries or neuropathies would receive conservative treatment.

For major orthopaedic complications requiring surgery, we observed probabilities of surgical failure of 24% for tendon rupture reconstruction<sup>48-53</sup> and 5% for carpal tunnel release<sup>54-61</sup>. For deep infection irrigation and debridement procedures, we estimated a failure rate of 44% based on studies that evaluated surgical effectiveness for wrist septic arthritis<sup>62,63</sup>. We assumed that 100% of patients had successful hardware removal for all three fixation methods when indicated. We used annual all-cause mortality rates from United States Life Tables<sup>64</sup> and adjusted them to 6-week time frames for the model.

### *Quality of life*

We derived optimal state quality of life values after 6-weeks and 1-year of fixation from recent studies (Table 1). When specific values were not available for the individual cycles in between 6-weeks and 1-year, we used linear interpolation up to the 1-year value. Our model applied time-dependent quality of life differences between optimal fixations from 6-weeks (i.e. 0.66 CRPP, 0.721 ORIF, 0.65 EF) up to the 1-year period (i.e. 0.862 CRPP, 0.854 ORIF, 0.89 EF) following fracture fixation<sup>3-6</sup>, after which we allowed patients to return to their baseline age-adjusted quality of life according to the Beaver Dam Health Outcomes Study<sup>65</sup>. We assumed the initial disutility of immobilization (e.g. casts after CRPP) would be captured by the 6-week quality of life values. Patients in the suboptimal state received a lower composite quality of life based upon the method's relative frequency of postsurgical complications or reduction loss (Table I).

Based on data from total wrist fusion and arthroplasty, quality of life values of successfully treated minor orthopaedic complications (e.g. superficial or pin track infection; tendonitis/tenosynovitis) for CRPP and EF were estimated to be equal to the optimal fixation quality of life value<sup>66</sup>, and failure of treatment resulted in a 3.2% loss in utility from optimal fixation<sup>12,66</sup>. Surgical site infections for ORIFs were estimated to result in a 7.2% drop in utility when treated successfully<sup>67,68</sup> and a further drop of 3.5% when the infection fails initial oral antibiotic treatment<sup>66</sup>. Like CRPP and EF, patients with successfully treated cases

of tendonitis following ORIF returned to optimal fixation utilities, but failure of conservative treatment caused an 11% loss in utility given need for hardware removal<sup>69</sup>. For non-operative major orthopaedic complications, we estimated 18% disutility for CRPS<sup>12</sup> and 13% disutility for non-operative nerve injuries or carpal tunnel syndrome treated conservatively<sup>70,71</sup>. For major orthopaedic complications requiring surgery, we estimated the utilities of successful tendon rupture reconstruction to be 0.683<sup>70</sup>, successful carpal tunnel release to yield a 10% loss in utility from baseline carpal tunnel syndrome values above<sup>66,70-75</sup>, and successful deep infection debridement to be a return to baseline optimal fixation<sup>66</sup>. Successful hardware removal for CRPP and EF were estimated to be a minimal loss of utility of 0.50%<sup>66</sup>, whereas for ORIF we estimated a 7% loss of utility from plate removal<sup>69</sup>. The composite utility value for each cycle of the suboptimal fixation group due to minor or major orthopaedic complications was the sum-total of the individual complication utility values as above multiplied by the relative frequency of each complication. For CRPP, EF, and ORIF, patients who failed corrective surgeries for major orthopaedic complications were attributed a quality of life utility of 0.5 given the range of disutilities associated with the health states of advanced wrist arthrosis and failed or complicated carpal tunnel releases<sup>74-77</sup>.

For revision ORIFs after CRPP and EF, we estimated that the quality of life lay at the midpoint between that of optimal primary fixation and optimal ORIF<sup>69</sup>. Since no data exist on quality of life for revision fixation ORIF after primary ORIF, we assumed a median 7.5% loss of quality of life<sup>78-81</sup>. Patients who live with failed fixation were attributed a quality of life of 0.7 given the composite risk of nonunion, malunion, and wrist arthritis<sup>69,82-84</sup>.

### *Costs*

We used Medicare reimbursement schedules to estimate unit costs of outpatient visits, imaging, laboratory tests, anesthesia and surgeon fees, surgery-related inpatient and outpatient technical costs,

post-operative care and evaluations, medical complications, orthopaedic complication treatments, and post-operative rehabilitation and physical therapy<sup>85-91</sup>. Frequency of resource use for each treatment was determined from expert surgeon consultation. Costs for revision fixation ORIFs were assumed to be equal to those of a primary ORIF.

We assumed that the costs of treating pin and surgical site infections would include a 7-day course of 250 mg cephalexin<sup>12</sup>. If antibiotics failed for CRPP/EF, we assumed pin removal for CRPP/EF; for ORIF, we assumed operative hardware removal, debridement and irrigation, IV antibiotics, external fixation, and an additional ORIF<sup>85,86,88,92</sup>. Costs of treating tendonitis or tenosynovitis conservatively included thumb spica or wrist casting, non-steroidal anti-inflammatory medications, and a single methylprednisolone injection up to 40 mg<sup>92-94</sup>. For CRPP and EF, failed tenosynovitis treatment required an additional methylprednisolone injection; for ORIF, failed tendonitis treatment required plate removal. Costs of treating CRPS included a 1-year course of 100 mg gabapentin and outpatient occupational therapy for desensitization. Costs of treating non-operative nerve injuries or conservatively-treated carpal tunnel syndrome included hand/wrist orthosis with a single injection of methylprednisolone up to 40 mg<sup>93,94</sup>.

For the societal perspective, we calculated productivity costs from the age-specific likelihood of labor force participation and average daily earnings<sup>95,96</sup> multiplied by average days out of work<sup>4,14,97</sup>. We calculated unpaid caregiver time-costs from average daily salary of a home health aide<sup>96,98</sup> multiplied by average days out of work<sup>4,14,97</sup>. Since all methods possess the same annual age-adjusted mortality, we ignored future consumption costs<sup>23,96</sup>. We expressed costs in 2016 U.S. dollars based on the Consumer Price Index<sup>99</sup> with a 3% discount rate for quality of life and costs.

### *Sensitivity Analyses*



We conducted one- and two-way deterministic sensitivity analyses on all transition probability, quality of life, and time parameters to validate assumptions and to evaluate the sensitivity of our results to variation of specific parameters. We varied transition probabilities and time values (e.g. days out of work) across all possible ranges found in the literature and utilities by 50% above and below base value. The period of time affected by fracture fixation (after which patient's return to their age-adjusted baseline quality of life according to the Beaver Dam Health Outcomes Study) was varied from the base value of 1-year up to 5-year time frames, utilizing long-term quality of life values of 0.94, 0.96, and 0.93 for CRPP, ORIF, and EF respectively<sup>12</sup>.

We also conducted probabilistic sensitivity analysis to evaluate the uncertainty in all input parameters simultaneously by repeating the cost-effectiveness analysis through 10,000 simulations. In each simulation, the model varied parameters of interest within pre-specified beta distributions centered around the base transition probability or quality of life value. We used a triangular distribution for the period of time affected by fracture fixation—centered at 1 year and extending to 5 years—and we used a gamma distribution for days out of work to model uncertainty of societal costs.

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## Results

### *Base Case*

Patients undergoing these procedures accumulated, after fixation, 13.99 lifetime QALYs for CRPP, 13.98 lifetime QALYs for ORIF, and 13.89 lifetime QALYs for EF (Figure 2). The mean procedural costs of uncomplicated procedures were \$7,638 for CRPP, \$10,170 for ORIF, and \$9,886 for EF. When considering costs of the procedure, complications, and revisions from the health care payer perspective, the total costs were \$8,735 for CRPP, \$11,125 for ORIF, and \$11,759 for EF (Figure 3). From this perspective, CRPP produces greater QALYs and fewer costs than both ORIF and EF and therefore dominates both alternatives (Table 2). From a societal perspective, ORIF costs the least at \$19,214 compared with \$19,435 for CRPP and \$22,295 for EF (Figure 3). The ICER for CRPP compared with ORIF is \$21,058 per QALY, below the WTP threshold of \$50,000. From this perspective, because EF is costlier (\$22,295) and produces fewer QALYs than both CRPP and ORIF, it remains dominated (Table 2).

### *Total QALYs Analysis*

Figure 2 provides the breakdown of average total QALYs generated by the model for CRPP, ORIF, and EF. The majority of the total QALYs for each fixation method is generated by optimal fixations: 12.1, 12.1, and 10.9 QALYs for CRPP, ORIF, and EF, respectively. Of note, ORIF has more contribution of average total QALYs from suboptimal fixations (1.68 QALYs, 12%) compared to CRPP (1.4 QALYs, 10%) due to long-term effects from major (non-operative) orthopaedic complications, namely nerve injury not requiring surgery, neuropathy, CRPS, and carpal tunnel syndrome treated conservatively. Both CRPP and EF have significant contributions of average total QALYs from revision fixations via ORIF (0.39 and 0.85 QALYs, respectively).

### *Total Cost Analysis*

Figure 3 provides a breakdown of total costs from the health care sector and societal perspectives. Total costs from the health sector perspective incorporate surgery procedural costs, costs of medical and orthopaedic complications, and costs of revision and failed fixations (total CRPP = \$8,735, ORIF = \$11,125, EF = \$11,759). Average total costs are primarily costs of the surgical procedures themselves (87.4%, 91.4%, and 84.1% for CRPP, ORIF, and EF, respectively). For CRPP and EF, revision ORIF fixation procedures following loss of reduction contributed an average of \$315 (3.6%) and \$686 (5.8%), respectively, but only \$108 (1.0%) for ORIF. Major (operative) complications, including costs of tendon reconstruction, nerve injury operations or carpal tunnel release, deep infection treatments and surgeries, and hardware removals contributed an average of \$567 (6.5%), \$493 (4.4%), and \$774 (6.6%) for CRPP, ORIF, and EF, respectively. Total costs from the societal perspective incorporate health care sector costs from above in addition to costs of lost productivity and costs of unpaid caregiving (total CRPP = \$19,435, ORIF = \$19,214, EF = \$22,295). From the societal perspective, costs of lost productivity contributed \$8,091 (41.6%) and \$7,967 (35.7%) for CRPP and EF, respectively, but only \$6,116 (31.8%) for ORIF.

### *Deterministic Sensitivity Analyses*

The cost-effectiveness analysis was sensitive to the rate of reduction loss, the rate of major (non-operative) orthopaedic complications, the optimal quality of life values up to the 1-year mark, and the number of days out of work. Figure 4A illustrates the sensitivity of the results to reduction loss after CRPP and ORIF. From the health care sector perspective and WTP threshold of \$100,000, ORIF only becomes preferred (defined as the cost-effective or dominant option) if reduction loss after CRPP increases from the base value of 4% to 16%. All other things being equal, even if ORIF reduction loss is 0%, CRPP is still preferred unless the reduction loss after CRPP exceeds roughly 14%. The societal perspective is less tolerant of reduction loss: the rate of reduction loss after CRPP would have to exceed only 5% at a WTP threshold of \$50,000 or 6.5% at a WTP threshold of \$100,000, for ORIF to become preferred.

Figure 4B illustrates the sensitivity of the results to major (non-operative) complications of CRPP and ORIF, which represents the combined rates of non-operative nerve injury, neuropathy, CRPS, and carpal tunnel syndrome treated conservatively. From a health-care sector perspective and WTP threshold of \$100,000, ORIF is preferred if this combined complication rate reduces from the base value of roughly 12% to 10%. The societal perspective is more sensitive to this value: if the ORIF base complication rate decreases by only 0.5%, then ORIF is preferred at the \$50,000 and \$100,000 willingness-to-pay thresholds.

From the health care perspective, if the optimal quality of life values up to the 1-year period after ORIF were valued 7.8% more at the \$50,000 WTP threshold or 4.4% more at the \$100,000 WTP threshold, then ORIF becomes the preferred method. The societal perspective is more sensitive to the quality of life difference: if the quality of life values after ORIF were valued 0.8% more at the \$50,000 WTP threshold or 1.2% more at the \$100,000 WTP threshold, ORIF becomes the preferred option. Other quality of life values did not alter the base case results when varied above and below 50% the base value.

When the days out of work between CRPP and ORIF are equal, CRPP is preferred at all WTP thresholds (Figure 5). The \$50,000 WTP threshold requires patients undergoing ORIF to miss approximately 12 fewer days of work for ORIF to be preferred. The \$100,000 WTP threshold requires an approximate difference of 14 days for ORIF to be preferred.

#### *Age-stratified analysis*

For a cohort of 25-year-old patients, CRPP dominated ORIF from a healthcare sector perspective, producing greater QALYs (21.19 vs. 21.17) at lower cost (\$8,689 vs. \$11,082). From the societal perspective, CRPP remained the dominant option with the same QALY differential at a lower total cost

(\$17,480 vs. \$17,728). For an older 65-year-old cohort, ORIF resulted in greater QALYs than CRPP (9.55 vs. 9.54) at higher cost (\$11,124 vs. \$8,733), generating an ICER of \$384,695/QALY, which is above the WTP thresholds of \$50,000 and \$100,000 per QALY. From the societal perspective, ORIF resulted in the same QALY differential for higher cost (\$14,998 vs. \$13,857), resulting in an ICER of \$200,786, which is also above the WTP thresholds.

#### *Probabilistic sensitivity analysis*

Figure 6 depicts the 10,000 iterations of the probabilistic sensitivity analysis when considering uncertainty for multiple parameters from the health care perspective. Figure 7 depicts the same 10,000 iterations of the probabilistic sensitivity analysis from the societal perspective. These data are organized into cost-effectiveness acceptability curves (Figure 8). In Figure 8A, from the health care sector perspective, ORIF has the greatest proportion of cost-effectiveness across higher WTP compared to CRPP and EF, although the gap between ORIF and CRPP is small. In Figure 8B, from the societal perspective, ORIF is the more cost-effective method at even lower WTP. However, there is only a 5 to 10% difference in frequency of combinations that find ORIF to be more cost-effective.

## Discussion, Conclusions, and Suggestions for Future Work

We investigated the cost-effectiveness of CRPP, ORIF, and EF for operative DRFs. From the health care payer perspective, accounting for total medical costs paid by third-party payers and patients out-of-pocket<sup>23</sup>, CRPP was both the cheapest and most effective option. From the societal perspective, including lost productivity and unpaid caregiving in addition to total medical costs, ORIF was the least costly procedure, but CRPP demonstrated greater effectiveness and was cost-effective with an ICER of \$21,058 per QALY. However, variations around certain parameters (e.g. rates of reduction loss and non-operative complications) make it difficult to distinguish CRPP from ORIF with great certainty across all scenarios. From both perspectives, EF as definitive treatment was the costliest and least effective.

CRPP is considered a relatively straightforward, inexpensive technique compared to the more invasive, costlier ORIF<sup>3,5,35</sup>. Our model confirms the cheaper procedural costs of CRPP, even when accounting for costs of non-operative complications and of additional surgeries for revision fixations and operative complications. As earlier studies have suggested<sup>6,14,16</sup>, our results demonstrate that considering the costs of lost productivity while out of work and of unpaid caregiving while immobilized supports ORIF to be the least costly technique at the societal level because of faster return to work and shorter immobilization periods. In our model, the benefit in earlier return to work for ORIF over CRPP was 10 days. However, the range of differences observed in the literature varies from 9-28 days<sup>4,14,100,101</sup>. Depending on the patient, age, occupation, and the value of earnings lost, a faster return to work could favor ORIF over CRPP in situations with high monetary cost or disutility of time out of work.

Despite documented efficacy<sup>4-6,30,102</sup>, CRPP has been associated with inferior ability to achieve and maintain reduction<sup>3,8,9,103</sup> with total complication rates as high as 30-50%<sup>104-106</sup>. After categorizing and tabulating complications from randomized controlled trials and prospective cohort studies identified by

systematic review, our model estimated more modest but still comparatively higher rates of reduction loss, minor complications (i.e. superficial infections, tendonitis/tenosynovitis), and major complications requiring surgery (i.e. tendon rupture, deep infections, carpal tunnel release or nerve repairs, operative hardware removal) for CRPP compared to ORIF. However, ORIF had a higher rate of major non-operative complications compared to CRPP owing mainly to a higher rate of non-operative nerve injury or neuropathy. A background rate of neuropathy is associated with DRFs from compression by hematoma, bony fragments, or soft-tissue swelling<sup>107</sup>, but studies have noted rates of mild to moderate median, radial, or ulnar nerve dysfunction ranging from 10-40% following ORIF<sup>6,33,39,108</sup>. In our model, the longitudinal disutility conferred by these nonsurgical complications drives the marginally lower total quality of life for ORIF versus CRPP in the base case and in the younger 25-year-old cohort. Lowering the ORIF rate of non-operative nerve injury, neuropathy, or CRPS by just 2% shifts the cost-effectiveness results in favor of ORIF. Likewise, stricter budgetary considerations (i.e. lower WTP) and higher valuations of productivity (i.e. societal perspective) are less tolerant of CRPP reduction loss >5% given the additional costs of revision fixation.

Probabilistic sensitivity analysis demonstrates uncertainty regarding the cost-effectiveness of CRPP vs. ORIF. When considering data uncertainty, there is only a 5 to 10% difference in the frequency of probability combinations that find ORIF to be more cost-effective from both health care and societal perspectives. The current degree of uncertainty in the data produces difficulty in distinguishing either strategy as being more cost-effective overall and thus may be left to the surgeon's experience and judgment per patient preferences, circumstances, and outcomes. Our model provides evidence-based reference ranges under which either ORIF or CRPP would be preferred to be used as an aid in shared-decision making.

Our results are to be viewed in light of some limitations. Lack of published data necessitated assumptions in certain transition probabilities and utilities as described in the methods. In the absence of data, we assumed that quality of life for conversions to ORIF after CRPP or EF could be approximated by the midpoint between the primary fixation (CRPP or EF) and primary ORIF<sup>69</sup>. Likewise, specific quality of life values were not available for complication states following primary fixation (e.g. CRPS). We used similar studies to estimate these values as a decrement from quality of life of the optimal fixation method (see Methods). We assumed that the probability of perioperative medical complications would be the same for CRPP and EF as ORIF, since these are due to comorbidities and not affected by fixation choice. We assumed that transition probabilities, quality of life, and costs for a revision ORIF would be similar to a primary ORIF. The sensitivity analyses in this study reflect the uncertainty and inconsistency in the data and have been incorporated into the conclusions. It is not clear whether QALYs are sensitive enough to detect functional differences between fixation methods for DRFs; there is a need for greater study into preference-based outcomes. Inherent to the tradeoffs in decision analytic methodology, we assumed that the probability of suffering a perioperative medical complication (e.g. stroke), an orthopaedic minor or major (operative or non-operative) complication, and a loss in reduction were mutually exclusive. We limited our data to studies that attempted to randomize across fracture types (e.g. intraarticular vs. extraarticular, degree of comminution) to avoid confounding. We acknowledge that specific DRFs inherently require certain treatment—for example, partial articular fractures with a volar shearing mechanism requiring open buttress plating. Our findings cannot be applied to all injuries without clinical judgment. We also acknowledge that lost productivity is a complex concept that is not fully captured by the valuation of age-stratified average daily earnings lost; more granular methods of valuation and more comprehensive evaluation of age-related effects are needed for future studies.



Previous cost-effectiveness studies of DRF fixation have been conflicting<sup>12-14</sup>. Our study finds that CRPP did have the highest likelihood of being cost-effective assuming a reduction loss rate <5%, a combined CRPS and non-operative nerve injury/neuropathy rate for ORIF >10%, and a 10-day delay in return to work for CRPP compared to ORIF. But given historical inconsistency regarding these parameters, it is difficult to distinguish ORIF or CRPP as the more cost-effective alternative in all scenarios, especially given the cost benefit provided by ORIF from shorter immobilization and faster return to work. We recommend that future studies work towards clarifying the extent of non-operative nerve injury, neuropathy, and CRPS following DRF surgical fixation and their effects on quality of life. Randomized-controlled trials with longer follow-up periods can assist in a better understanding of the long-term effects of surgical fixation of DRFs.

**Summary**

Options for surgical fixation for distal radius fractures (DRFs) includes closed reduction percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF). There is no consensus on the optimal fixation method for patients with DRFs requiring surgery. Despite no longterm functional benefit, there is a growing trend in the orthopaedic community for ORIF given new volar locking plate technology and the belief that ORIF provides more durable fixation, shorter immobilization, and faster return to work. Our study utilized cost-effectiveness analysis methodology to determine which of CRPP, ORIF, and EF provides the best value. In the base case, CRPP does have the highest likelihood of being cost-effective when accounting for both direct (health care payer perspective) and indirect (societal perspective) costs. However, given inconsistency in the literature regarding key postsurgical parameters such as reduction loss rate, CRPS and non-operative nerve injury/neuropathy rate, and days out of work; it is difficult to distinguish ORIF or CRPP as the more cost-effective alternative in all scenarios, especially given the cost benefit provided by ORIF from shorter postsurgical immobilization and faster return to work. Surgeons should therefore discuss procedure choice with patients based on individual patient-physician circumstances, preferences, and outcomes.

## Appendix

### *Systematic Review Methodology*

We utilized the PubMed interface to search the MEDLINE interface. The search terms were grouped into two broad categories: [Distal radius fractures] and [Fixation method]. The search build for distal radius fractures included: ((distal[All Fields] AND ("radius fractures"[MeSH Terms] OR ("radius"[All Fields] AND "fractures"[All Fields]) OR "radius fractures"[All Fields]) OR "Colles fracture"[All Fields])). The search build for each fixation method was the following: ((closed[All Fields] AND reduction[All Fields] AND percutaneous[All Fields] AND pinning[All Fields]) OR ((K wire[All Fields] OR Kirschner[All Fields]) AND (fixation[All Fields] OR percutaneous[All Fields]))) for CRPP; (external[All Fields] AND fixation[All Fields]) for EF; and (((("open fracture reduction"[MeSH Terms] OR ("open"[All Fields] AND "fracture"[All Fields] AND "reduction"[All Fields]) OR "open fracture reduction"[All Fields] OR ("open"[All Fields] AND "reduction"[All Fields]) OR "open reduction"[All Fields]) AND ("fracture fixation, internal"[MeSH Terms] OR ("fracture"[All Fields] AND "fixation"[All Fields] AND "internal"[All Fields]) OR "internal fracture fixation"[All Fields] OR ("internal"[All Fields] AND "fixation"[All Fields]) OR "internal fixation"[All Fields])) OR volar plating[ti] OR palmar plat\*[ti] OR "volar locking plate"[ti]) for ORIF. Each fixation method was searched individually with the terms for DRF, which yielded a total of 1252 studies, of which 226 were duplicates, therefore resulting in a grand total of 1026 studies.

These 1026 studies underwent a rigorous screening process by title and abstract. Our inclusion criteria were: 1) a clinical study of CRPP, EF, and/or ORIF fixation methods for operative DRFs across all populations and fracture types; 2) reported post-operative complication and/or reduction loss rates; 3) was a randomized controlled trial or prospective study; and 4) was reported in English. If there was any question regarding the inclusion of a study, we retrieved and reviewed the full text of the article in question to determine eligibility. Per the first two inclusion criteria, we excluded case reports (83), non-

clinical studies including methodological studies, reviews, meta-analyses, and cadaveric/biomechanical studies (219), studies that did not focus on DRFs alone (127), studies that did not specifically analyze operative fixation of DRFs (109), studies focused on newer or variant fixation techniques (162), studies focused on the elderly population only (15), studies focused on the pediatric population only (42), studies of fixation in specific fracture patterns (167), studies that failed to report fracture patterns (3), studies that failed to report clinical complications (17), studies that included open fractures (3), and studies whose full texts were not accessible (13). This resulted in 66 studies that met the first two inclusion criteria.

In order to maximize the quality of literature used to derive parameters for the model, we limited our data abstraction to randomized controlled trials and prospective cohort studies only (inclusion criterion 3). We stratified our 66 studies by level of evidence: level I randomized controlled trials (16), level II prospective cohort studies (18), level III retrospective studies (20), and level IV case series (9). Three studies were determined to be a second publication of the same dataset and were excluded. This resulted in a grand total of 34 level I and level II studies that were thoroughly reviewed in order to derive the data inputs into our model.

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## Tables

Table 1. Base Case Input Parameters\*

	CRPP	ORIF	EF
<b>Suboptimal transition probabilities</b>			
Loss of reduction**	4% <sup>3-6,8,31,32,35,109,110</sup>	1% <sup>4-6,11,15,32-39,41,111-113</sup>	11% <sup>3,11,31,33,34,39-41,114-116</sup>
Minor complication++	11% <sup>3-6,8,32,35,42</sup>	7% <sup>4-6,8,11,15,33-39,41,112,113,117</sup>	10% <sup>3,11,31,33,34,39,41,43-45,115,116,118,119</sup>
Major complication (non-operative)†	10% <sup>3,5,6,8,32,35,42,110,120</sup>	12% <sup>5,6,8,11,15,32-41,111-113,120</sup>	16% <sup>3,11,33,34,39-41,43-45,115,118,119</sup>
Major complication (operative)‡	6% <sup>3-6,31,35,42,109,120</sup>	5% <sup>4-6,11,15,33-41,111-113,117,120</sup>	11% <sup>11,31,33,36,39-41,43-45,116,118</sup>
<b>Quality of life (utilities)§</b>			
Optimal fixation, 6 weeks	0.66 <sup>14</sup>	0.721 <sup>14,39</sup>	0.65 <sup>39</sup>
Optimal fixation, 1 year	0.862 <sup>14</sup>	0.854 <sup>13,14,39</sup>	0.89 <sup>39</sup>
Suboptimal fixation (minor or major complication), 6 weeks	0.560 <sup>12-14,66,70,71,73-75,77</sup>	0.615 <sup>12-14,39,66,70,71,73-75,77</sup>	0.552 <sup>12,39,66,70,71,73-75,77</sup>
Suboptimal fixation (loss of reduction), 6 weeks	0.618 <sup>69,82,83</sup>	0.666 <sup>69,82,83</sup>	0.606 <sup>69,82,83</sup>
<b>Procedural costs (2016 USD)</b>			
Pre-operative work-up#	\$252 <sup>85-87</sup>	\$252 <sup>85-87</sup>	\$252 <sup>85-87</sup>
Anesthesia costs	\$129 <sup>89,90</sup>	\$173 <sup>89,90</sup>	\$152 <sup>89,90</sup>
Surgery costs	\$3,443 <sup>86,88,121</sup>	\$5,655 <sup>86,88,121</sup>	\$5,655 <sup>86,88,121</sup>
Surgeon fee	\$696 <sup>85,86</sup>	\$874 <sup>85,86</sup>	\$611 <sup>85,86</sup>
Post-operative care###	\$105 <sup>85,86,92</sup>	\$105 <sup>85,86,92</sup>	\$105 <sup>85,86,92</sup>
Post-acute rehab/physical therapy	\$3,014 <sup>85,91,122,123</sup>	\$3,112 <sup>85,91,122,123</sup>	\$3,112 <sup>85,91,122,123</sup>
<b>Productivity costs (2016 USD per day)</b>			
Base case (50-year old)	\$190 <sup>95,96</sup>	\$190 <sup>95,96</sup>	\$190 <sup>95,96</sup>
25-year old	\$147 <sup>95,96</sup>	\$147 <sup>95,96</sup>	\$147 <sup>95,96</sup>
65-year old	\$59 <sup>95,96</sup>	\$59 <sup>95,96</sup>	\$59 <sup>95,96</sup>
<b>Unpaid caregiver costs (2016 USD per day)</b>	\$61 <sup>96,98</sup>	\$61 <sup>96,98</sup>	\$61 <sup>96,98</sup>
<b>Time</b>			
Average days out of work	42 <sup>4,14,97</sup>	32 <sup>4,14,97</sup>	40 <sup>4,14,97</sup>

\*CRPP = closed reduction and percutaneous pinning, ORIF = open reduction internal fixation, and EF = external fixation. When multiple sources of data were available, we pooled data and weighted by sample sizes. We limited our literature to include volar locking plates for ORIF and bridging external fixation with or without supplementary pins for EF.

\*\*The probability of the fracture to lose reduction within a 6-week period following surgical fixation.

++The probability of the patient to suffer a minor orthopaedic complication (superficial pin or wound infection, tenosynovitis/tendonitis) within a 6-week period following surgical fixation.

†The probability of the patient to suffer a major orthopaedic complication that does not require a revision surgery (CRPS, non-operative nerve injury, neuropathy, or carpal tunnel syndrome) within a 6-week period following surgical fixation.

‡The probability of the patient to suffer a major orthopaedic complication requiring revision surgery (tendon rupture, nerve injury/carpal tunnel release, deep infection, or hardware removal) within a 6-week period following surgical fixation.

§Utility values experienced in each health state after 6-week cycles. Note that within the model, the optimal values were time-dependent and linearly increased with each 6-week cycle up to the 1-year time period after which patients received their background quality of life<sup>65</sup>. Suboptimal fixation utilities represent a composite decrement from the corresponding optimal fixation utility based upon the fixation method's relative frequency of complications or reduction loss.

#Pre-operative work-up includes the costs of an initial pre-operative level 3 visit, pre-operative x-rays, routine venipuncture, and laboratory screen for electrolytes, complete blood count, and coagulation factors.

##Post-operative care includes the costs of postsurgical analgesia and post-operative x-rays.

**Table 2.** Results of base case cost-effectiveness analysis between closed reduction percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF) methods for operative distal radius fractures from health care perspective (**upper panel**) and societal perspective (**lower panel**)\*.

<i>Health care sector perspective</i>			
	<b>Total QALYs</b>	<b>Total costs</b>	<b>ICER (\$/QALY)</b>
<i>CRPP</i>	13.99	\$8,735	-
<i>ORIF</i>	13.98	\$11,125	Dominated+
<i>EF</i>	13.89	\$11,759	Dominated

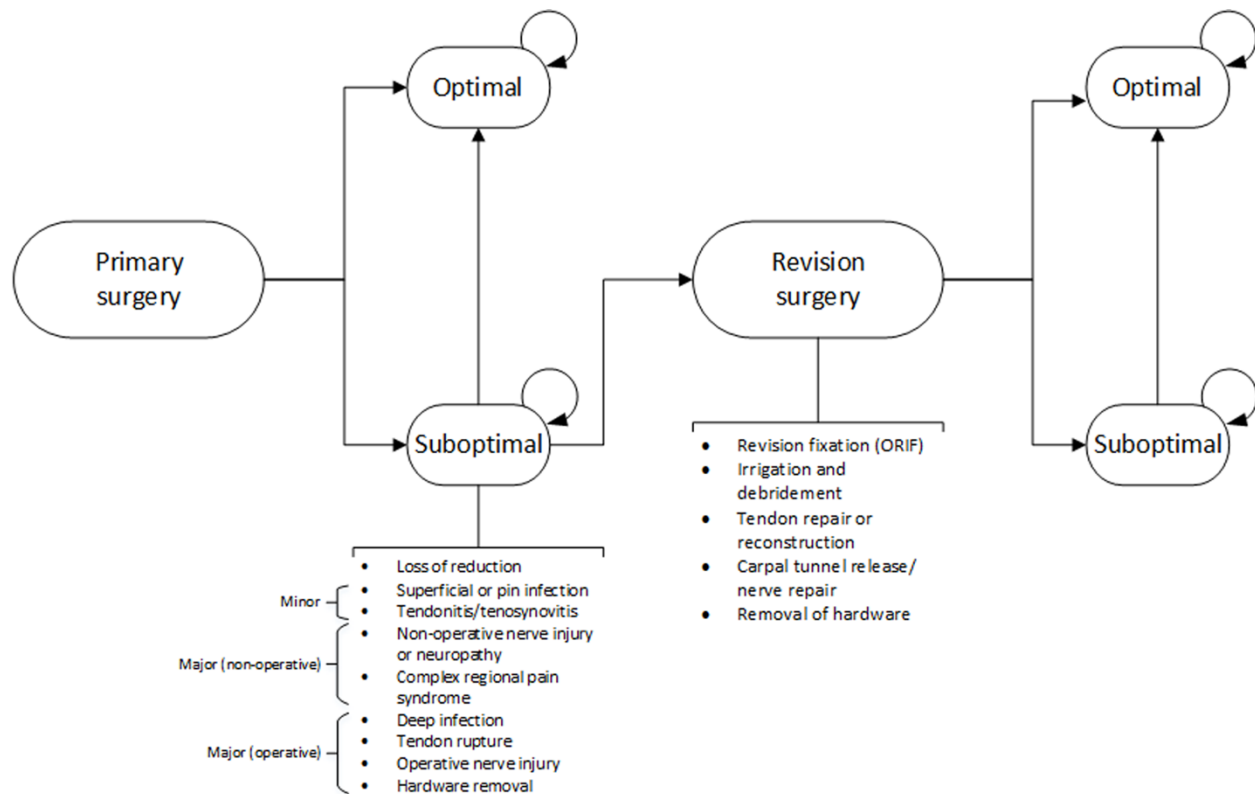
  

<i>Societal perspective</i>			
	<b>Total QALYs</b>	<b>Total costs</b>	<b>ICER (\$/QALY)</b>
<i>ORIF</i>	13.98	\$19,214	-
<i>CRPP</i>	13.99	\$19,435	\$21,058
<i>EF</i>	13.89	\$22,295	Dominated

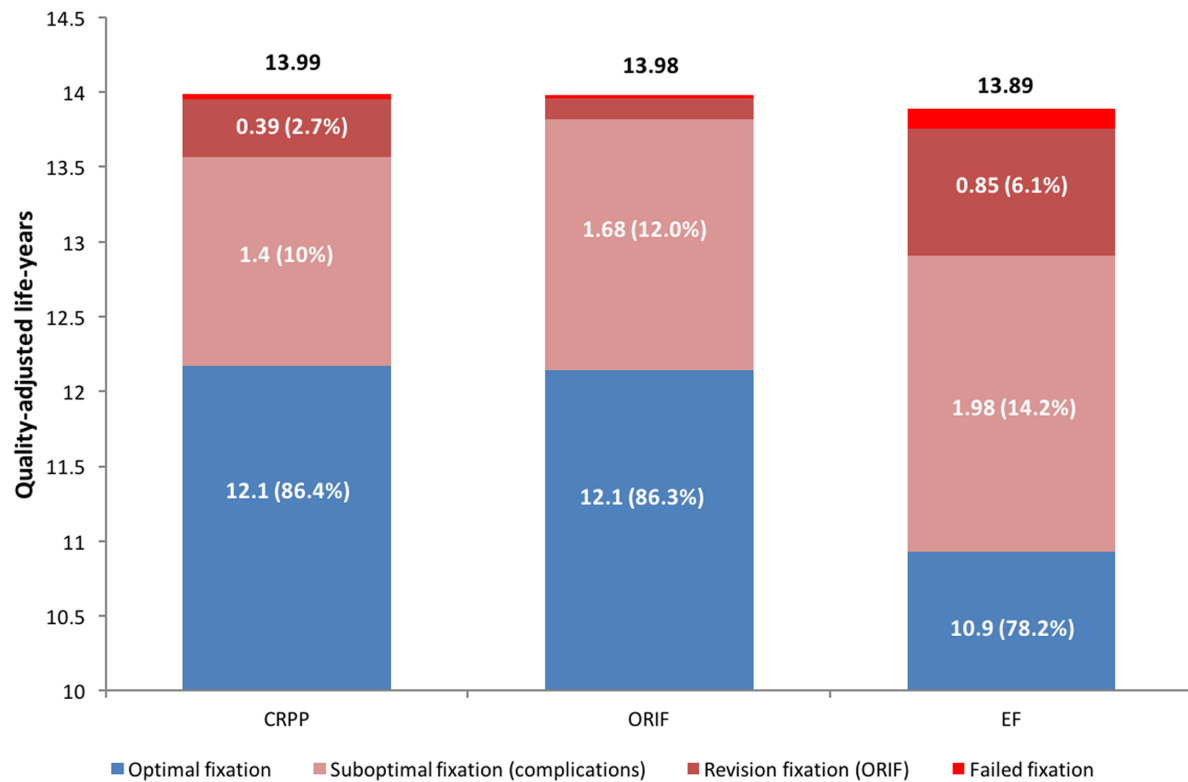
\*QALY = quality-adjusted life-year; ICER = incremental cost-effectiveness ratio.

+An intervention is dominated when it costs more and produces fewer QALYs than a comparative intervention.

## Figures

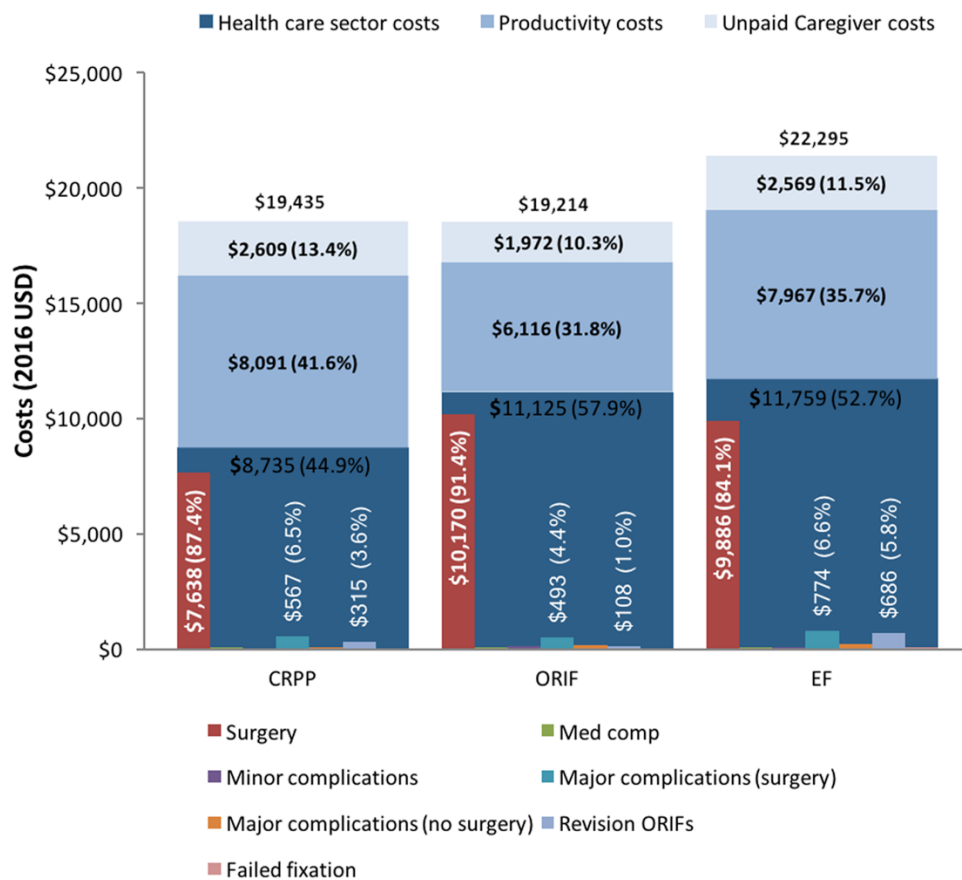


**Figure 1.** General schematic of the Markov model used to evaluate cost-effectiveness of closed reduction percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF) methods for operative distal radius fractures over 6-week cycles. Patients start the model at initial surgery and can transition to optimal and suboptimal health states. Patients receiving successful treatment of complications can progress to an optimal state or can remain in a suboptimal state. Patients receiving revision surgery for loss of reduction or major (operative) complications can experience optimal and suboptimal health states. Patients not receiving revision fixation or again experiencing loss of reduction following revision fixation remain with failed fixation (not pictured). Over each 6-week period, patients can remain within their health states or may die from age-adjusted all-cause mortality (not pictured). Direct arrows indicate transitions between health states; curved arrows indicate stasis within a health state.

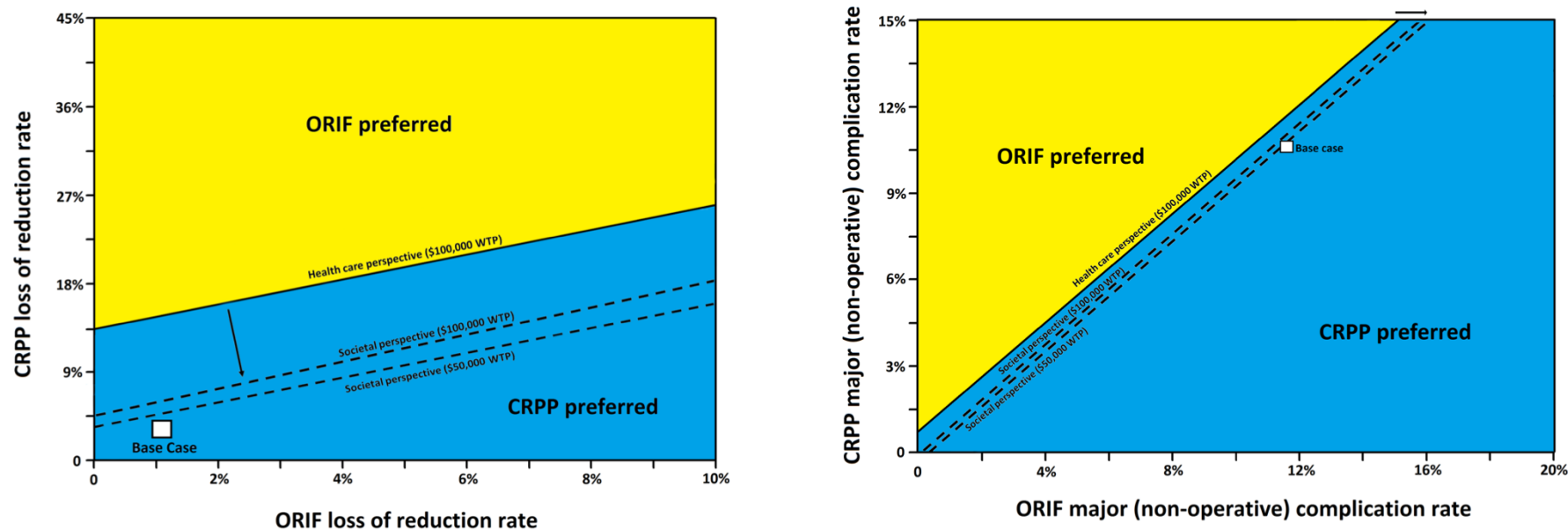


**Figure 2.** Analysis of total QALY outputs from the cost-effectiveness analysis of closed reduction percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF) methods (total CRPP = 13.99, ORIF = 13.98, EF = 13.89 QALYs).

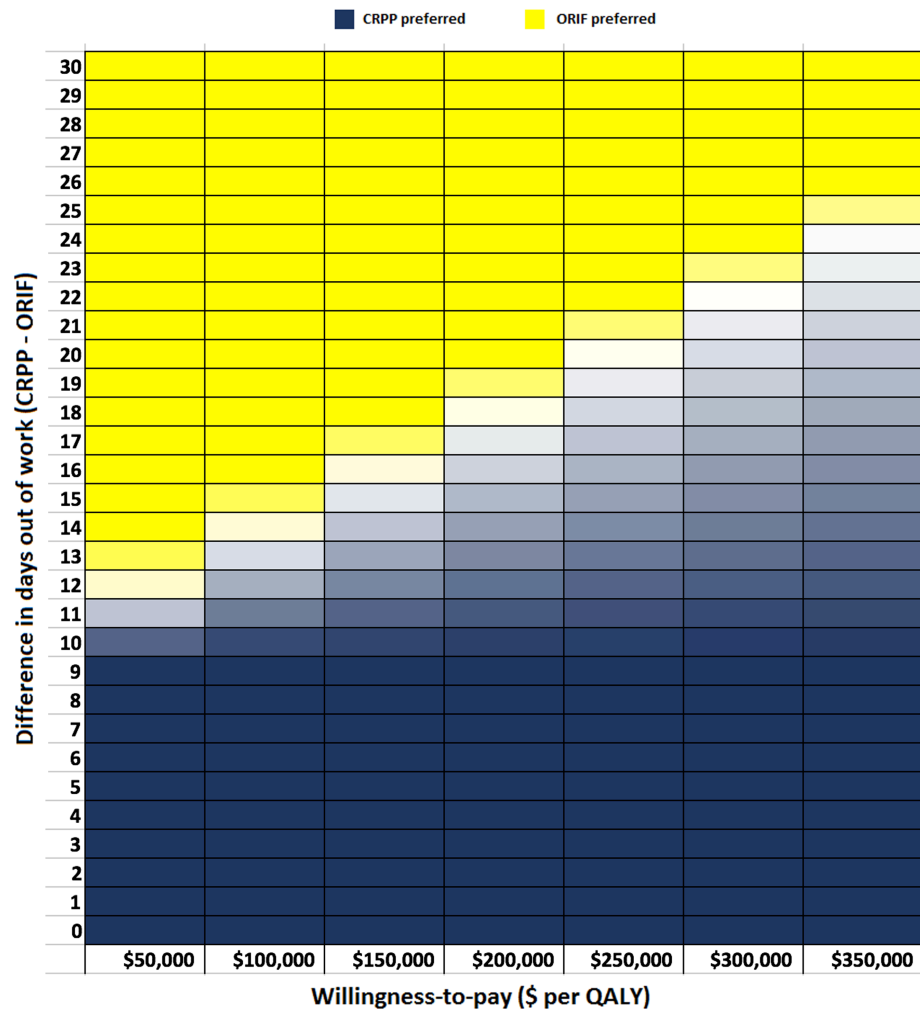




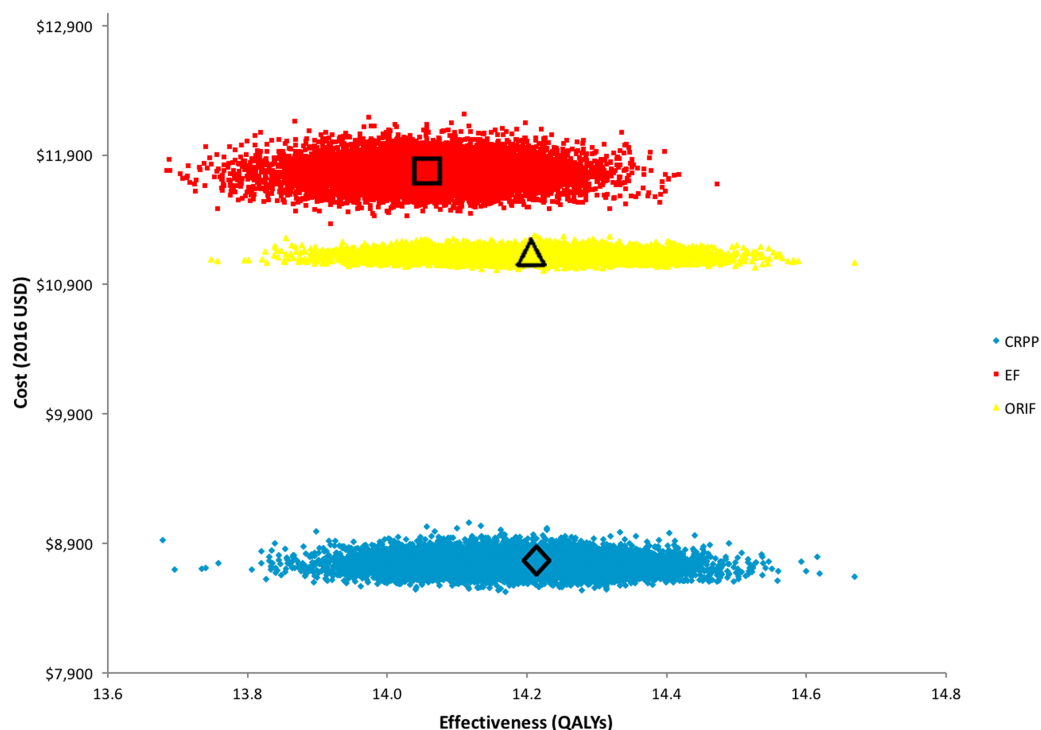
**Figure 3.** Analysis of total cost outputs from cost-effectiveness analysis of closed reduction percutaneous pinning (CRPP), open reduction internal fixation (ORIF), and external fixation (EF) methods. Health care sector costs incorporate costs of the surgical procedure, perioperative medical and postsurgical orthopaedic complication costs, and costs of revision and failed fixation. Societal costs incorporate health care sector costs in addition to costs of lost productivity and of unpaid caregiving.



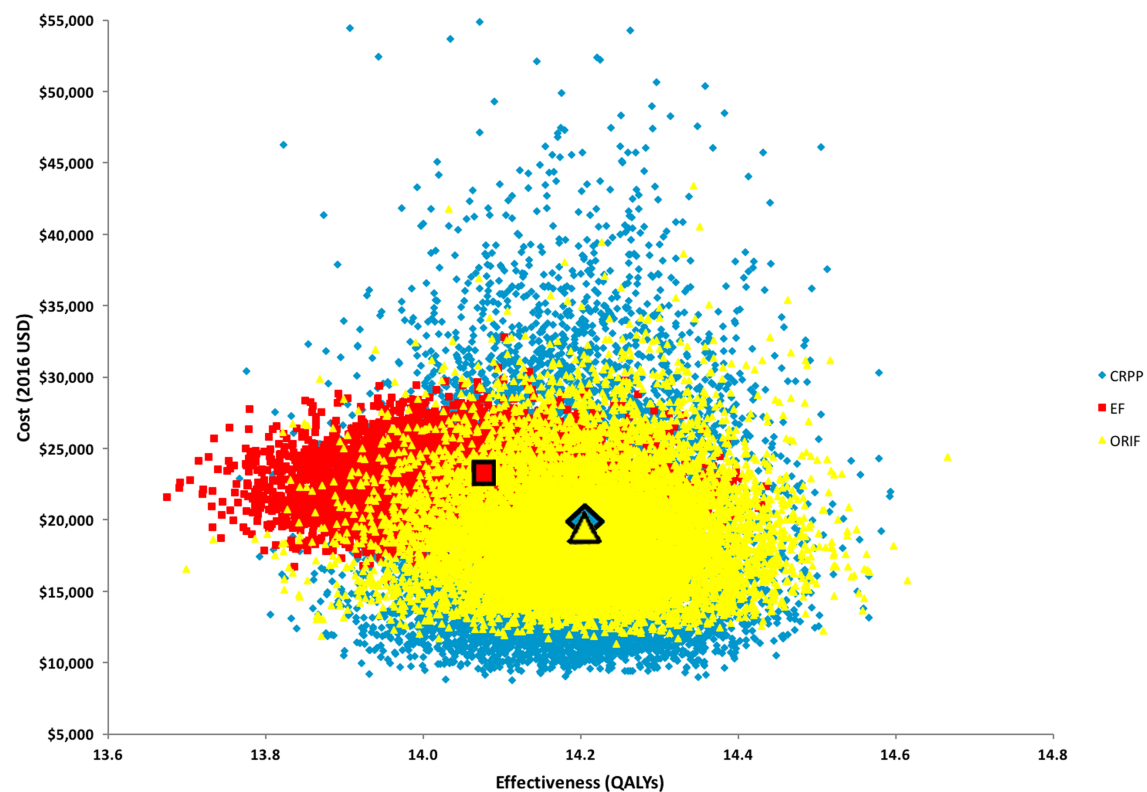
**Figure 4.** Two-way deterministic sensitivity analysis demonstrating preferred fixation method when simultaneously varying two variables at a given willingness-to-pay threshold from the health care and societal perspectives. **(A, Left)** Sensitivity analysis of the rates of reduction loss for CRPP and ORIF. Base case: CRPP loss of reduction rate = 4.1%; ORIF loss of reduction rate = 1.4%. **(B, Right)** Sensitivity analysis of the rates of major (non-operative) complications for CRPP and ORIF. Base case: CRPP major (non-operative) complication rate = 10.5% (5.2% non-operative nerve injury/neuropathy/carpal tunnel syndrome; 5.3% complex regional pain syndrome); ORIF major (non-operative) complication rate = 11.7% (9.7% non-operative nerve injury/neuropathy/carpal tunnel syndrome; 2.0% complex regional pain syndrome).



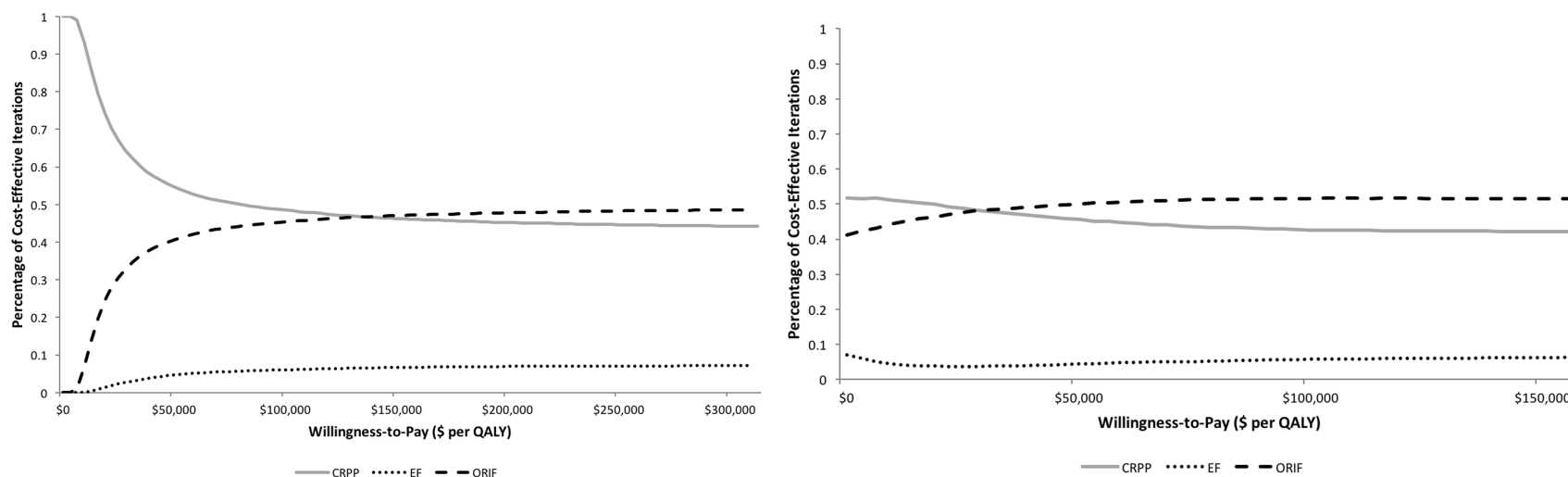
**Figure 5.** Heat index indicating preferred method between CRPP (blue) or ORIF (yellow) based on WTP threshold when varying the difference in numbers of days out of work between CRPP and ORIF. When the ICER for CRPP crosses the WTP threshold (white), the preference switches to ORIF. Stricter budgetary considerations or higher valuations of productivity (i.e. lower WTP) correspond to a smaller tolerable difference in days out of work between CRPP and ORIF.



**Figure 6.** Probabilistic sensitivity analysis scatter plot illustrating cost-effectiveness results of 10,000 iterative runs from the health care sector perspective that incorporates uncertainty around multiple parameters: probability of reduction loss, probability of major (non-operative) complications, probability of plate removal for tendonitis after ORIF, quality of life 1-year after optimal fixation, and the period of time affecting the quality of life after fracture and its fixation. Mean cost-effectiveness results for CRPP, ORIF, and EF are represented by the large diamond, triangle, and square, respectively. ORIF was on average costlier (\$11,123 v. \$8,738) for roughly the same effectiveness (14.2 QALYs).



**Figure 7.** Probabilistic sensitivity analysis scatter plot illustrating cost-effectiveness results of 10,000 iterative runs from the societal perspective that additionally incorporates uncertainty around the number of days out of work. Mean cost-effectiveness results for CRPP, EF, and ORIF are represented by the large diamond, square, and triangle, respectively. ORIF was on average less costly (\$19,196 vs. \$19,387) than CRPP with roughly the same effectiveness (14.2 QALYs).



**Figure 8.** Cost-effectiveness acceptability curves showing the percentage of the 10,000 probabilistic sensitivity analysis runs that demonstrated cost-effectiveness across various willingness-to-pay thresholds. **(A, Left)** Acceptability curve of the health care perspective incorporating uncertainty around multiple parameters: probability of reduction loss, probability of major (non-operative) complications, probability of plate removal for tendonitis after ORIF, quality of life 1-year after optimal fixation, and the period of time affecting the quality of life after fracture and its fixation. **(B, Right)** Acceptability curve of the societal perspective incorporating the additional uncertainty around the number of days out of work for each fixation method.

